The ILC Project

Benno List, DESY

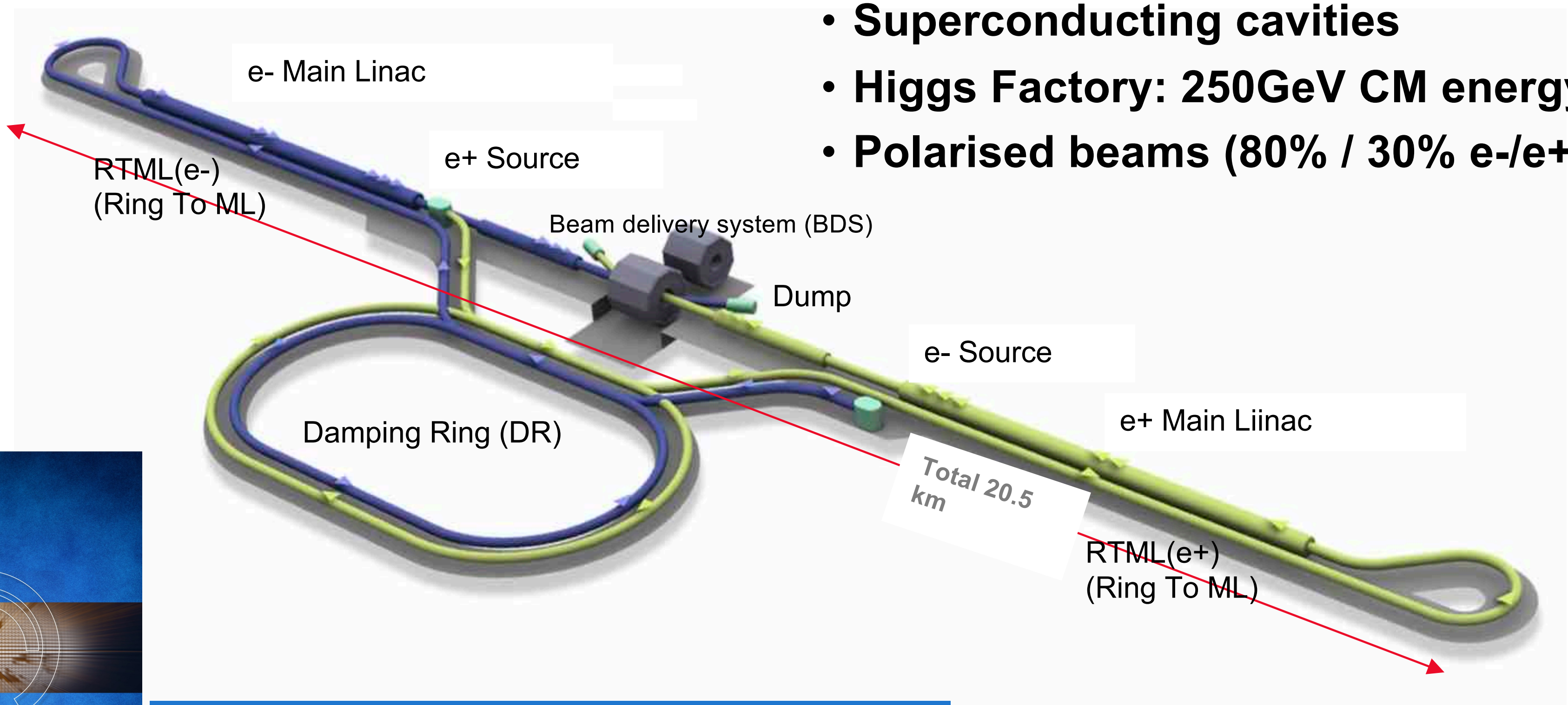
Joint Discussion with AF

Snowmass Energy Frontier Workshop – Restart

Sep 1, 2021

The International Linear Collider

- **e^+e^- linear collider**
- **Superconducting cavities**
- **Higgs Factory: 250GeV CM energy**
- **Polarised beams (80% / 30% e-/e+)**



Delivers canonical Higgs factory physics programme prioritized by European Strategy

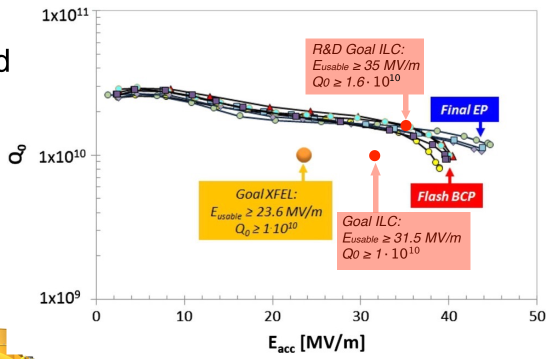
Key technologies

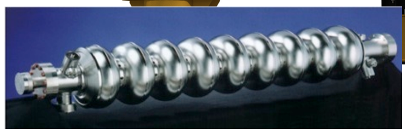
- **Superconducting RF – main linac**
- **Nanobeams – damping rings and final focus**

Technological Readiness: Key Technologies are Proven

SCRF Technology: Available on Industrial Scale

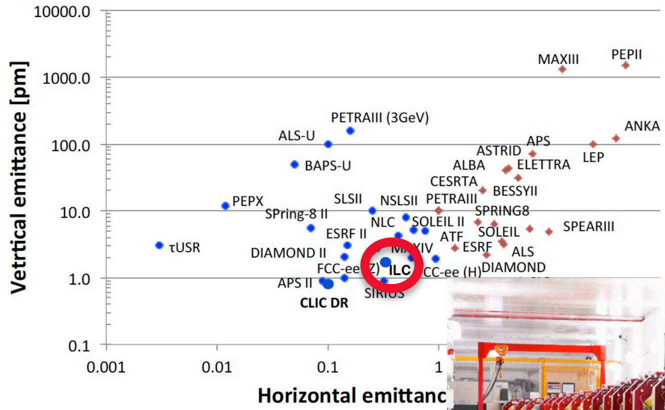
35MV/m Gradient and 10^{10} Quality factor proven



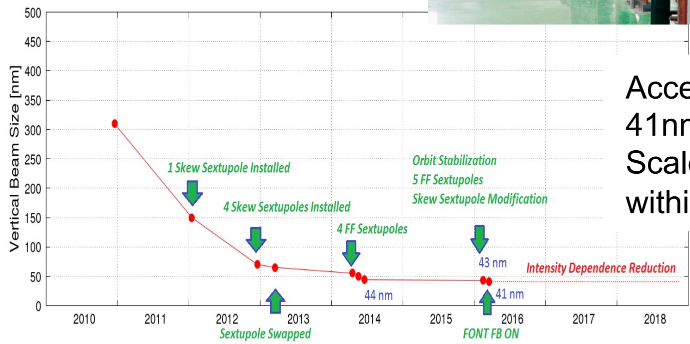


Cavity and Cryomodules built by industry

Nanobeam Technology



Damping Ring emittance comparable to photon sources

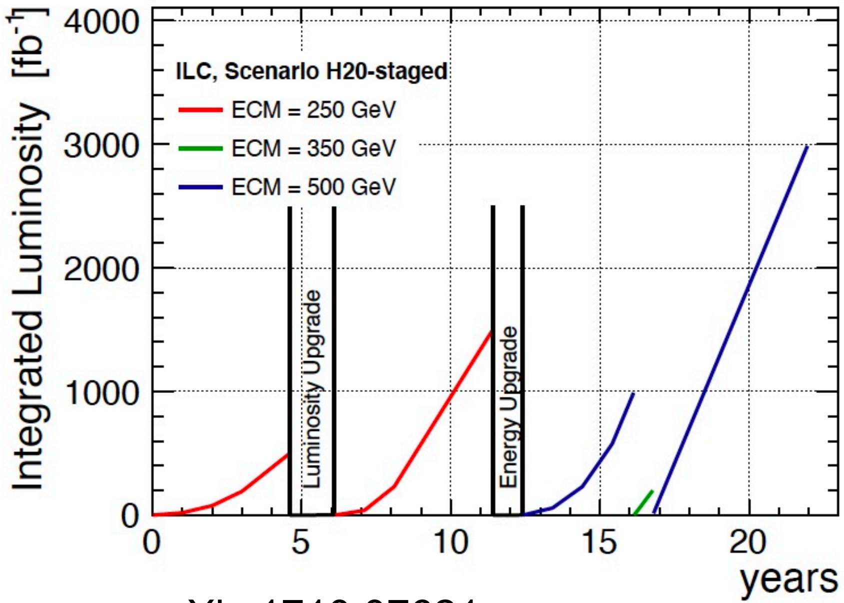


Accelerator Test Facility 2:
41nm beam size
Scaled to ILC energy: within 10% of design goal

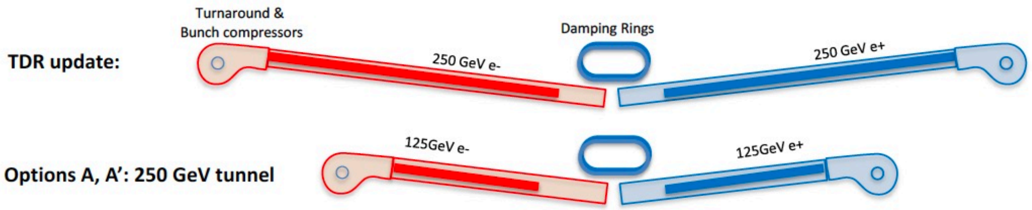
Upgradeable in Energy and Luminosity

- Possible energy upgrades: 500GeV, 1TeV
  -> need tunnel extension
- Tunnel can be built while running

- Luminosity upgrades:
  - More RF: factor 2 (1.35 -> 2.7E34)
  - + Run 500GeV machine at 250GeV, 10Hz: factor 2 (2.7E34 -> 5.4E34)
  - Improves power efficiency



arXiv:1710.07621



arXiv:1711.00568

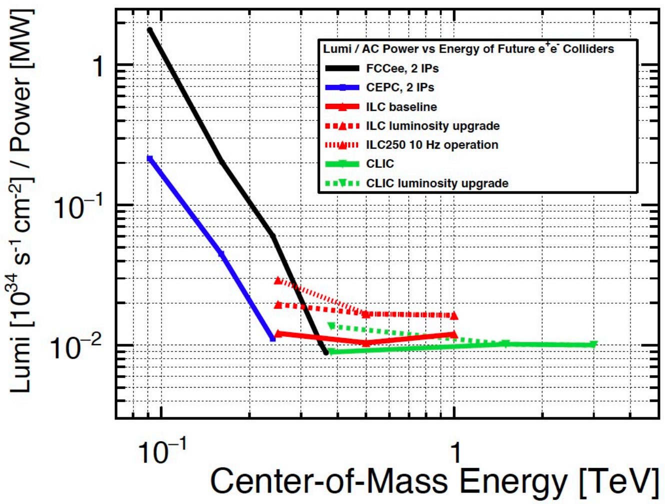
Energy Efficient and Affordable

Sustainability

Superconducting technology for energy conservation

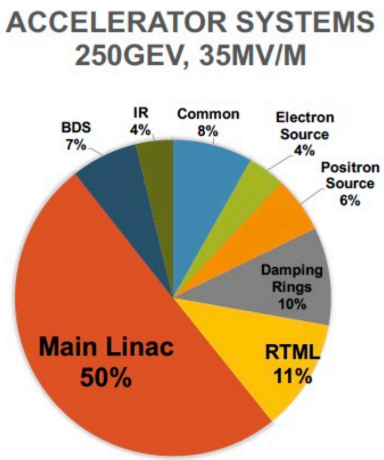
110MW wall plug power at 250GeV

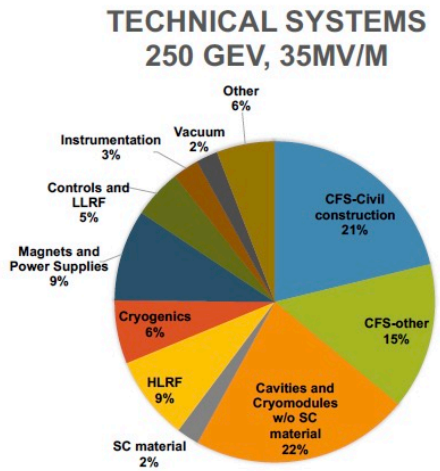
https://green-ilc.in2p3.fr/home/



Best lumi/power ratio
above 300GeV

Costs





arXiv:1903.01629

Total cost, estimated by ILC advisory panel, Japan*

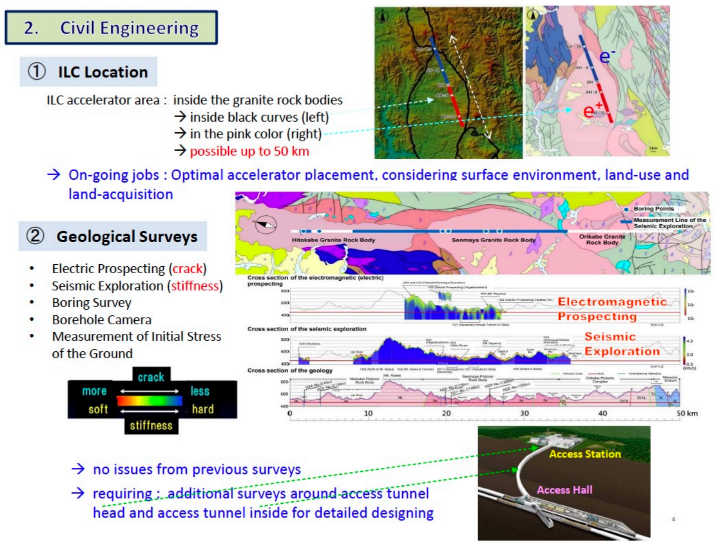
635-703G¥ (6.35-7.03G$),
including human ressources

(*) https://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_2_1.pdf

Ready for Construction

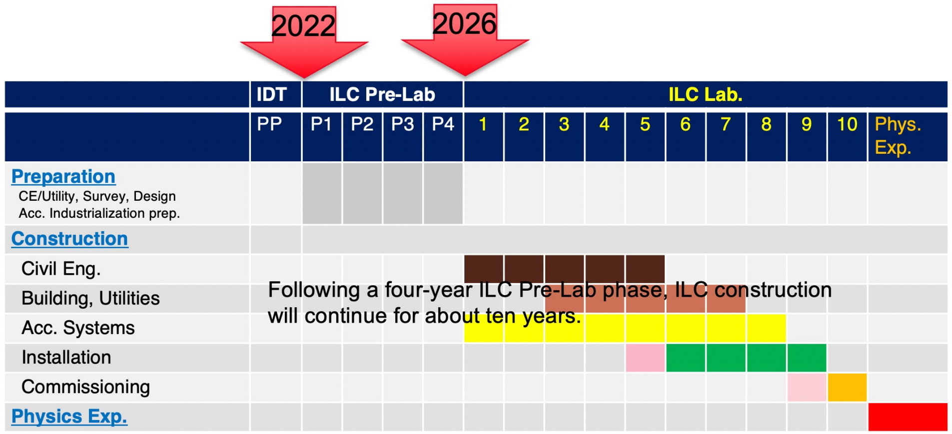
Site in Kitakami

Candidate site identified
50km space for 1 TeV
Geology is excellent



Schedule

- 4 year Pre-Lab (hosted by KEK, Japan) phase for R&D, Engineering Design Report, Construction preparation
- ILC Laboratory (international): 10 year construction phase
- Ready for Physics in 2036



An International Project

International Development Team

- Mandated by ICFA
- Prepares Pre-Lab

Active Working Groups on => Welcoming your participation!

- Physics, Detectors, Software
- Accelerator Topics

Recent Developments

- Pre-Lab Proposal submitted to MEXT
- Continuing support from DOE and State Dpt.
- MEXT contacted several European funding agencies to initiate consultations

A mature project ready to go

BACKUP

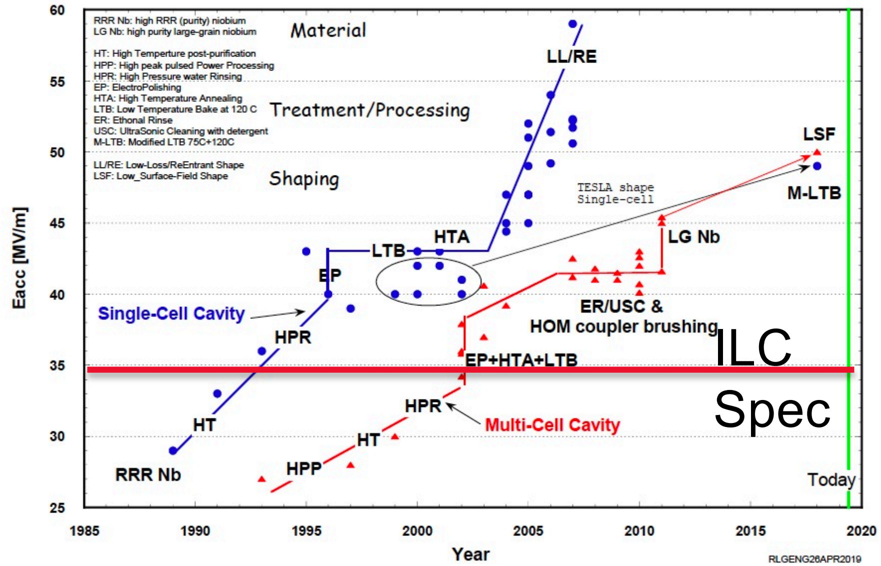
ILC Parameters for Reference

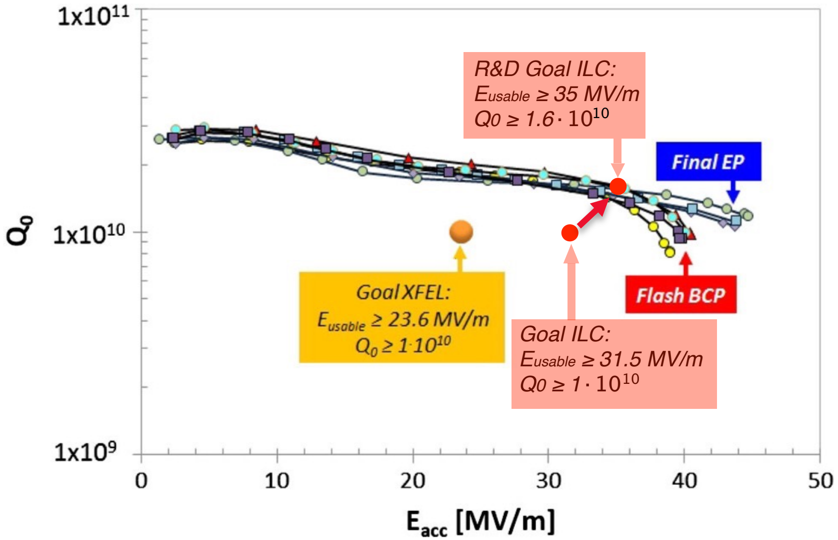
Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrades	Energy Upgrades	
Centre of mass energy	$\sqrt{s}$	GeV	250	250	500	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7 / 5.4	1.8 / 3.6	4.9
Polarisation for $e^-(e^+)$	$P_-(P_+)$		80 %(30 %)	80 %(30 %)	80 %(30 %)	80 %(20 %)
Repetition frequency	f_{rep}	Hz	5	5 / 10	5	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312 / 2625	2450
Bunch population	N_{e}	10^{10}	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	366	554/366	366
Beam current in pulse	I_{pulse}	mA	5.8	5.8	5.8 / 8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	897
Average beam power	P_{ave}	MW	5.3	10.5 / 21	10.5 / 21	27.2
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	5	10	10
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	35	30
RMS hor. beam size at IP	σ^*_{x}	nm	516	516	474	335
RMS vert. beam size at IP	σ^*_{y}	nm	7.7	7.7	5.9	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	58.3 %	44.5 %
Energy loss from beamstrahlung	δ_{BS}		2.6 %	2.6 %	4.5 %	10.5 %
Site AC power	P_{site}	MW	111	138 / 198	173 / 215	300
Site length	L_{site}	km	20.5	20.5	31	40

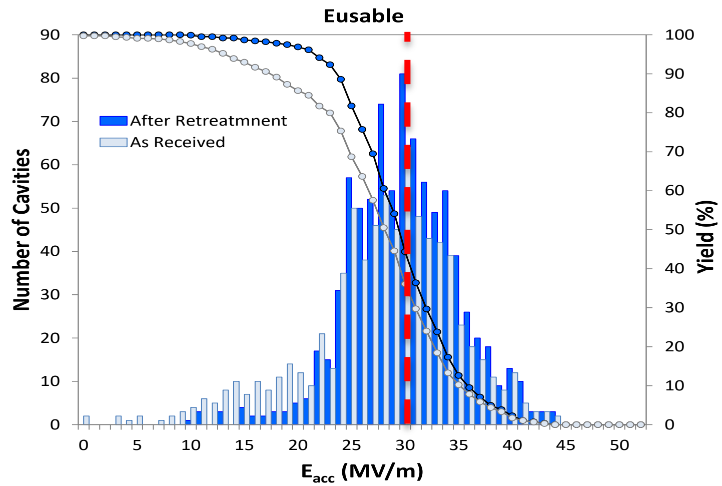
arXiv:1903.01629, AC power updated

Technology challenge: High gradient, high Q_0, high yield

- Baseline specification: 31.5MV/m, Q_0=1E10, 90%yield
- With new surface treatments: 35MV/m, Q_0=1.6E10 -> yield?
- >2000 cavities produced world wide, for FLASH, E-XFEL, LCLS-II, …
- R&D pushes performance limits
- Mass production still a challenge

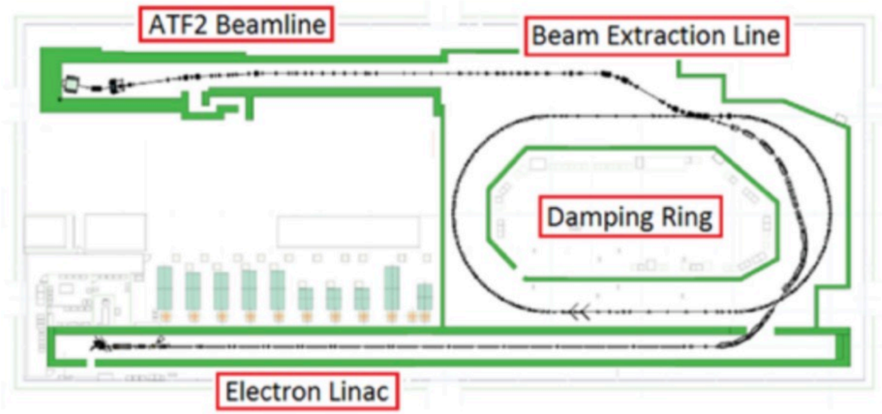


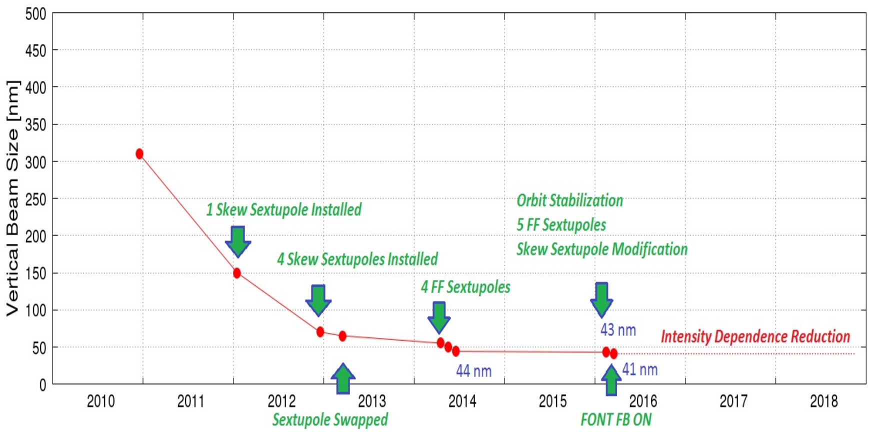




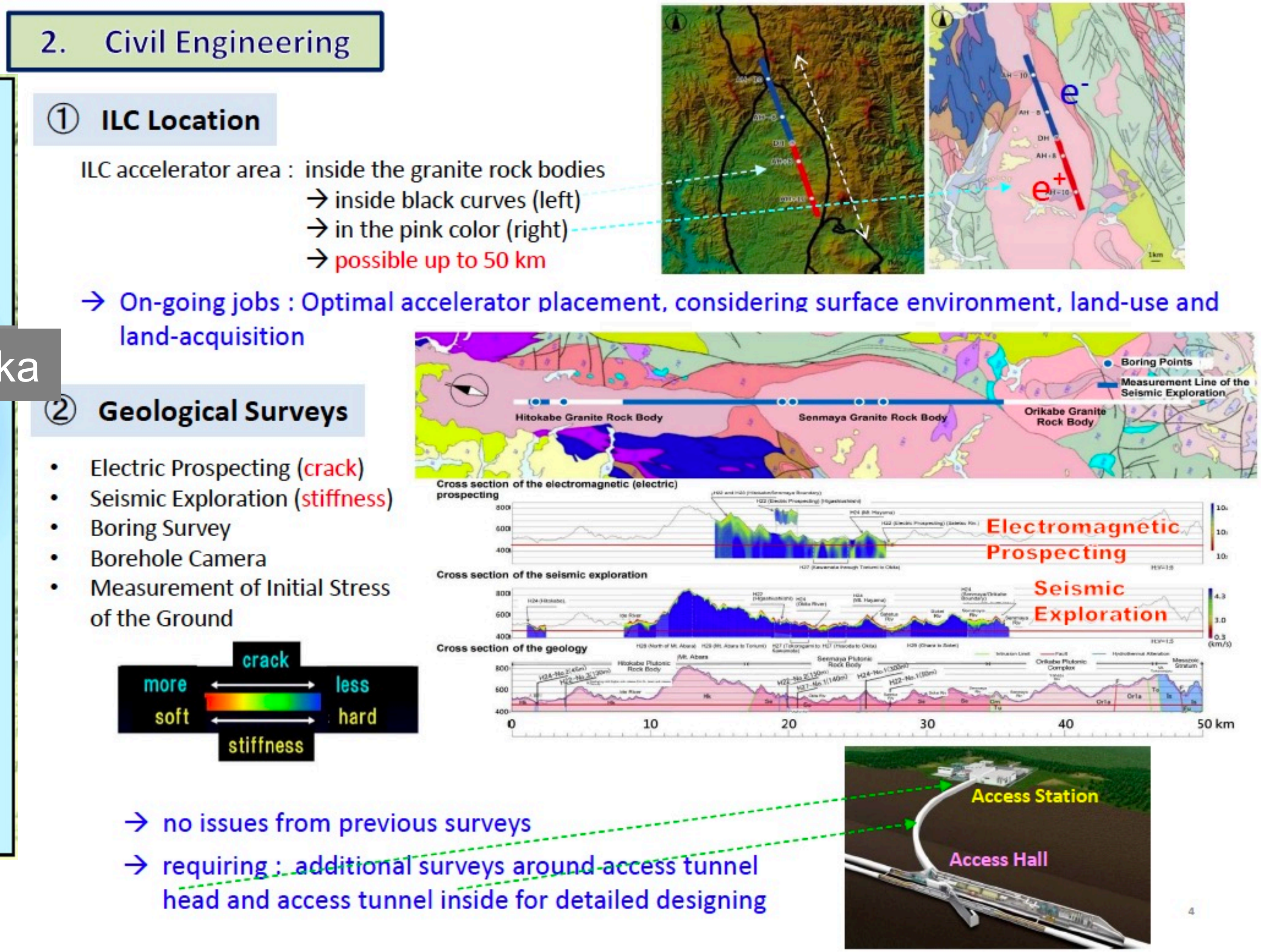
Nanobeam Technology

- ILC: 516 x 7.7 nm^2 beamspot @ 250GeV
- CLIC: 149 x 2.9 nm @ 380GeV
- Nanobeams are common challenge
- Accelerator Test Facility 2 (ATF-2) at KEK as test bed & demonstrator
  - 41nm beamsize at 1.3GeV (ILC goal corresponds to 37nm)
  - 2nm stabilisation with feedback possible





ILC: Site Selection and Civil Engineering



A. Suzuki, LCWS 2021, https://indico.cern.ch/event/995633/contributions/4240506/

From LCC to the Pre-Lab Proposal

- 2013-Jun 2020: Linear Collider Collaboration LCC under ICFA Mandate,
  governed by Linear Collider Board LCB
- 2014-2018: MEXT appointed ILC Advisory Panel reviews project, incl. new 250GeV baseline
- Feb-Jun 2020: LCB proposes International Development Team IDT to prepare an ILC-Pre-Lab
- Aug 2020: ICFA establishes IDT and appoints IDT Executive Board (*)
- Goal: establish an ILC Pre-Lab within ~1.5 years
- IDT focusses on ILC realization,
  KEK provides support (admin., financial)
- June 2021: IDT submits Pre-Lab proposal

Reminder for ICFA mandate for the IDT

- Clarifying the function and organisation of the ILC Pre-Lab based on the KEK International Working Group report,
- Developing a common understanding for the condition to start the ILC Pre-Lab,
- Providing an international framework for the ILC accelerator effort and coordinating further R&D and engineering design work for the ILC in order to sustain the community effort and to guarantee a smooth transition to the ILC Pre-Lab phase,
- Providing an international framework for the ILC physics and detector activities and coordinating physics and detector R&D effort in order to sustain the community effort and guarantee a smooth transition to the ILC Pre-Lab phase,
- Discussing with international partners (e.g. universities, national and regional laboratories)
  for resources needed for the ILC Pre-Lab, and
- Providing necessary information to the national authorities to support their discussion of the establishment of the ILC Pre-Lab.

T. Nakada: https://indico.cern.ch/event/995633/contributions/4240503/

(*) https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_August_2020.pdf

The Pre-Lab Proposal

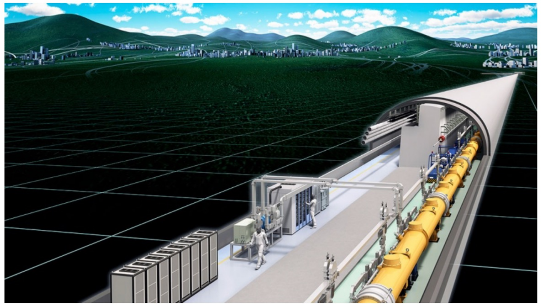
- Purpose of the Pre-Lab:
  - *To bring the technical and engineering work of the ILC project to a point where the construction can be started.*
- Mandate:
  - *Completion of **technical preparations** and production of engineering design documents for the accelerator complex*
  - *Compilation of design studies and documentation of the **civil engineering and site** infrastructure work, and of the **environmental impact assessment***
  - *Community guidance to develop the **ILC physics programme** that will fully exploit its potential*
  - *Provision of **information to national authorities** and to Japanese regional authorities to facilitate development of the ILC Laboratory*
  - *Coordination of **outreach** and communication work*

ILC International Development Team publishes the Proposal for the ILC Preparatory Laboratory

1 June 2021 - ILC International Development Team

An international scientific consensus supports an electron-positron Higgs Factory as the highest-priority next collider, and timely construction of the International Linear Collider (ILC) hosted in Japan is strongly supported by the international community.

Today, the international effort to realise ILC in Japan took another step forward with the publication of the document titled "Proposal for the ILC Preparatory Laboratory (Pre-lab)". This proposal is prepared by the ILC International Development Team (ILC-IDT) and endorsed by the International Committee for Future Accelerators (ICFA).



"The IDT has achieved the major milestone of completing this proposal, which outlines the organisational framework, an implementation model and a work plan of the Pre-lab", said Tatsuya Nakada, Chair of the IDT Executive Board and Professor Emeritus at École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland.

All the technical development and engineering design needed for the start of the construction of the ILC laboratory should be completed during the preparatory phase. In the same period, governmental authorities of interested nations are expected to forge an agreement on the sharing of the cost and responsibilities for the construction and operation of the ILC facility and

https://www.interactions.org/press-release/ilc-international-development-team-publishes-proposal-ilc

Proposal for the ILC Preparatory Laboratory (Pre-lab)

International Linear Collider
International Development Team

1 June 2021

Abstract

During the preparatory phase of the International Linear Collider (ILC) project, all technical development and engineering design needed for the start of ILC construction must be completed, in parallel with intergovernmental discussion of governance and sharing of responsibilities and cost. The ILC Preparatory Laboratory (Pre-lab) is conceived to execute the technical and engineering work and to assist the intergovernmental discussion by providing relevant information upon request. It will be based on a worldwide partnership among laboratories with a headquarters hosted in Japan. This proposal, prepared by the ILC International Development Team and endorsed by the International Committee for Future Accelerators, describes an organisational framework and work plan for the Pre-lab. Elaboration, modification and adjustment should be introduced for its implementation, in order to incorporate requirements arising from the physics community, laboratories, and governmental authorities interested in the ILC.

1

https://doi.org/10.5281/zenodo.4742043
arXiv:2106.00602

The Technical Preparation Plan

- Technical Preparation Plan:
  addendum to the Pre-Lab proposal by
  IDT WG2 (accelerators)
- Outlines the technical work to be conducted during the Pre-lab phase
- Defines 18 R&D work packages in 5 areas:
  - Main Linac and Superconducting RF
  - Sources
  - Damping Rings
  - Beam Delivery System
  - Dumps
- Emphasis on critical issues identified by ILC advisory panel
- Aim: establish international collaboration to perform critical R&D during Pre-Lab phase
- International in-kind contributions

https://doi.org/10.5281/zenodo.4742018

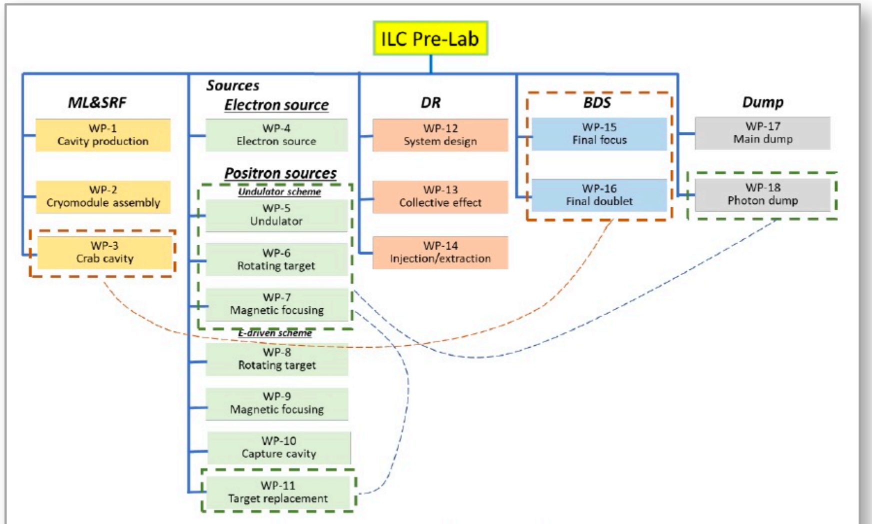
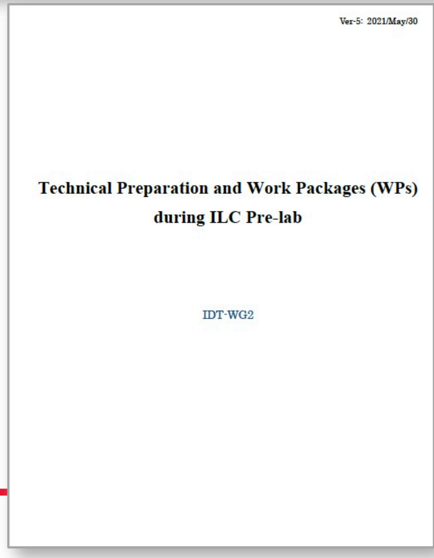


Figure 2: Summary of work packages.


Ver-5: 2021/May/30

Technical Preparation and Work Packages (WPs) during ILC Pre-lab

IDT-WG2

ILC Main Linac: Superconducting RF Technology

- ~8000 superconducting 9-cell cavities:
  1.3 GHz, 1.038m long, 31.5MV/m
- 9 cavities per 12m long cryomodule
- 10MW pulsed klystron per 4½ modules
- 2K operating temperature
  -> 4-6 cryo plants 19kW@4.5K
- Pulsed operation, 5Hz x 0.73ms

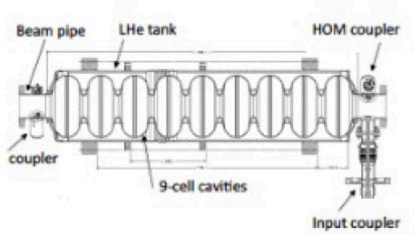
- European XFEL: 10% prototype in operation
  100 cryomodules, 800 cavities
- LCLS-II, SHINE: Under construction / planned

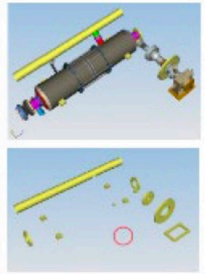

ILC: artistic view


E-XFEL: Reality

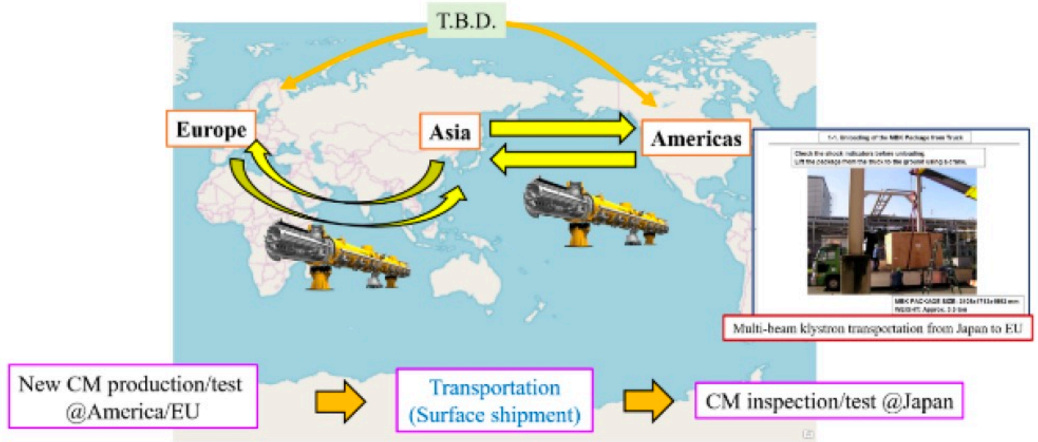
R&D on Main Linac and Superconducting RF

- Establish readiness of SRF technology for industrial production in Asia, Europe and Americas:
- WP01 Cavity Production
  - Produce 3x40 cavities with ILC specifications
  - Improve Q0 and gradient
- WP02 Cryomodule assembly
  - Build 3x2 ILC type cryomodules
  - “Cryomodule transportation program”: ship 1 cryomodule/region to Japan, operate it
- WP03 Crab cavity
  - Develop crab cavity design for interaction region



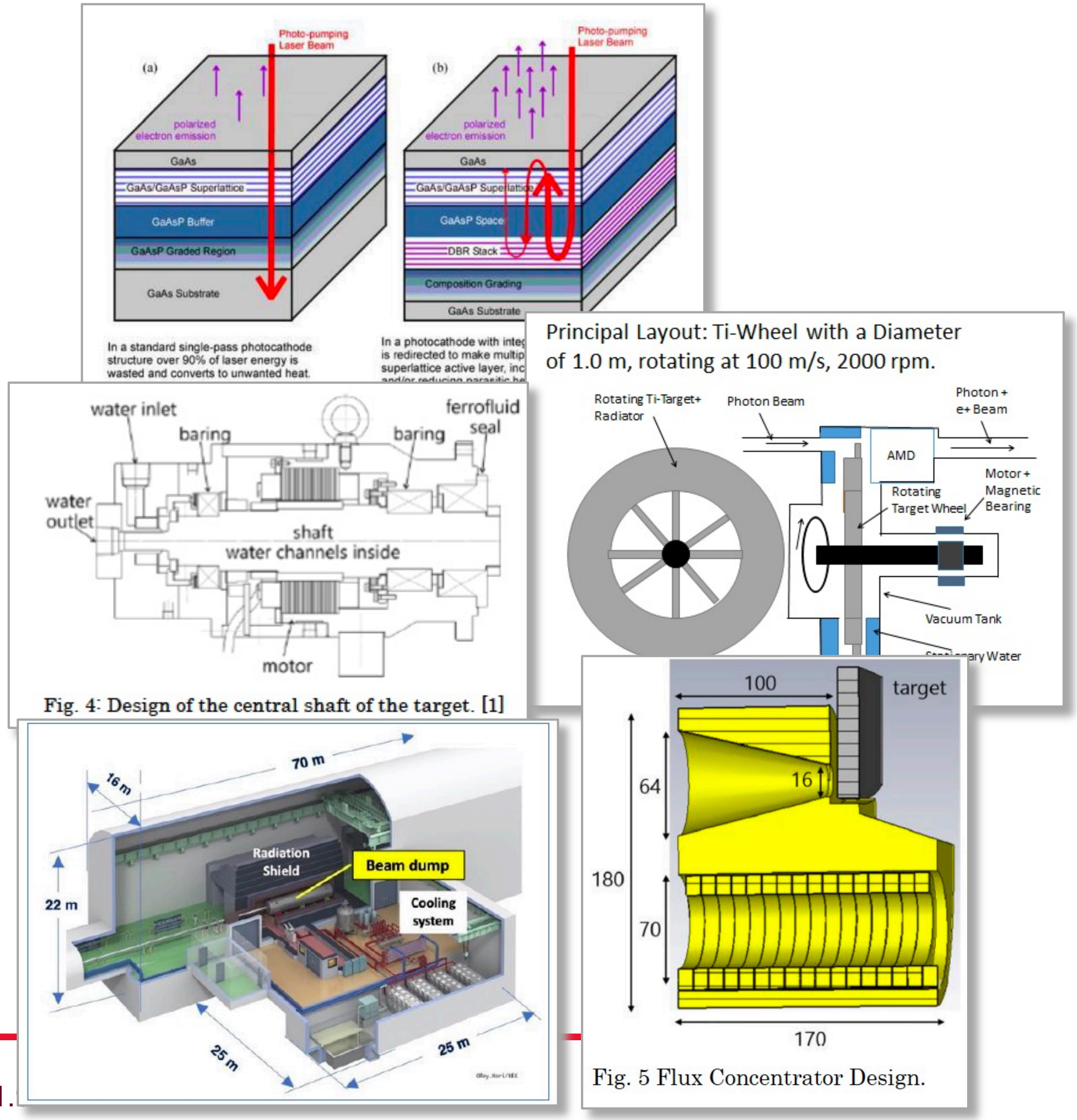


Item	TDR Baseline
Cavity shape	TESLA
Length	Fixed, L = 1,247 mm (61 mm shorter than XFEL)
Beam pipe flange	Fixed
Suspension pitch	Fixed
Tuner	Blade
Coupler flange (cold end)	40 mm
Coupler pitch	Fixed
He –in-line joint	Fixed



Sources and Dumps

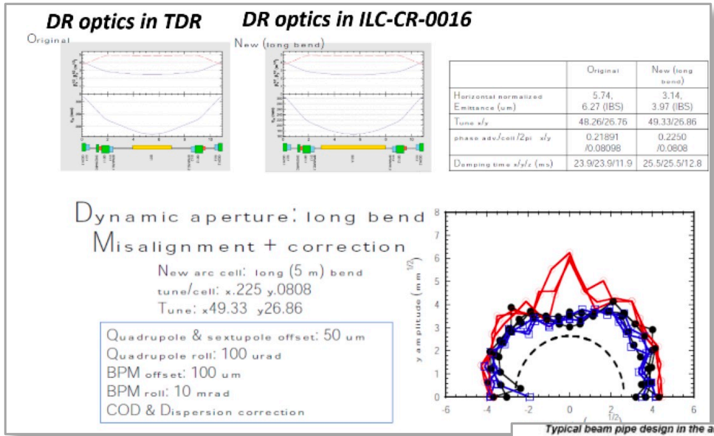
- Electron source: Demonstrate laser-driven polarised electron gun design with a prototype
- Positron Source: 2 Concepts
  - Undulator Positron source (polarized): Demonstrate feasibility of target and capture device
  - Electron driven source: Demonstrate feasibility, design capture linac
  - Develop remote target handling concept
- **Decide on positron source concept for initial operation**
- Dumps:
  - Engineering design of 17MW main beam dump
  - Design photon dump for undulator source

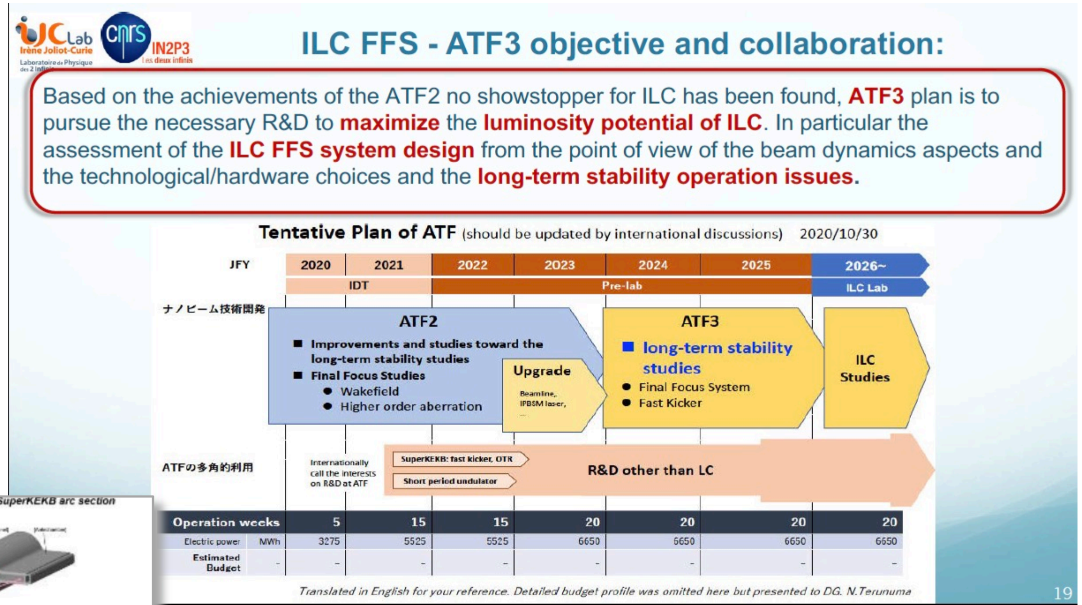


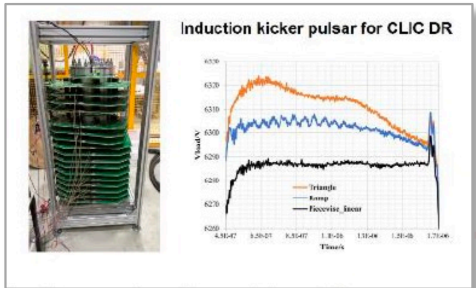
Damping Rings and Beam Delivery System

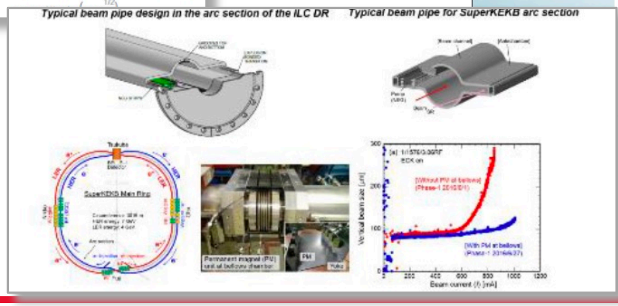
- Damping Rings:
  - Lattice and system design for damping rings
  - Evaluate permanent magnet option
  - Investigate and mitigate instabilities from collective effects (electron, fast ion)
  - Design fast kickers for injection and extraction

- Beam Delivery System:
  - Design the final focus system and test the final focus concept at **ATF-3**
  - Optimize the final focus doublet magnets, including prototypes

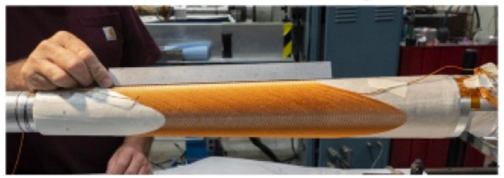




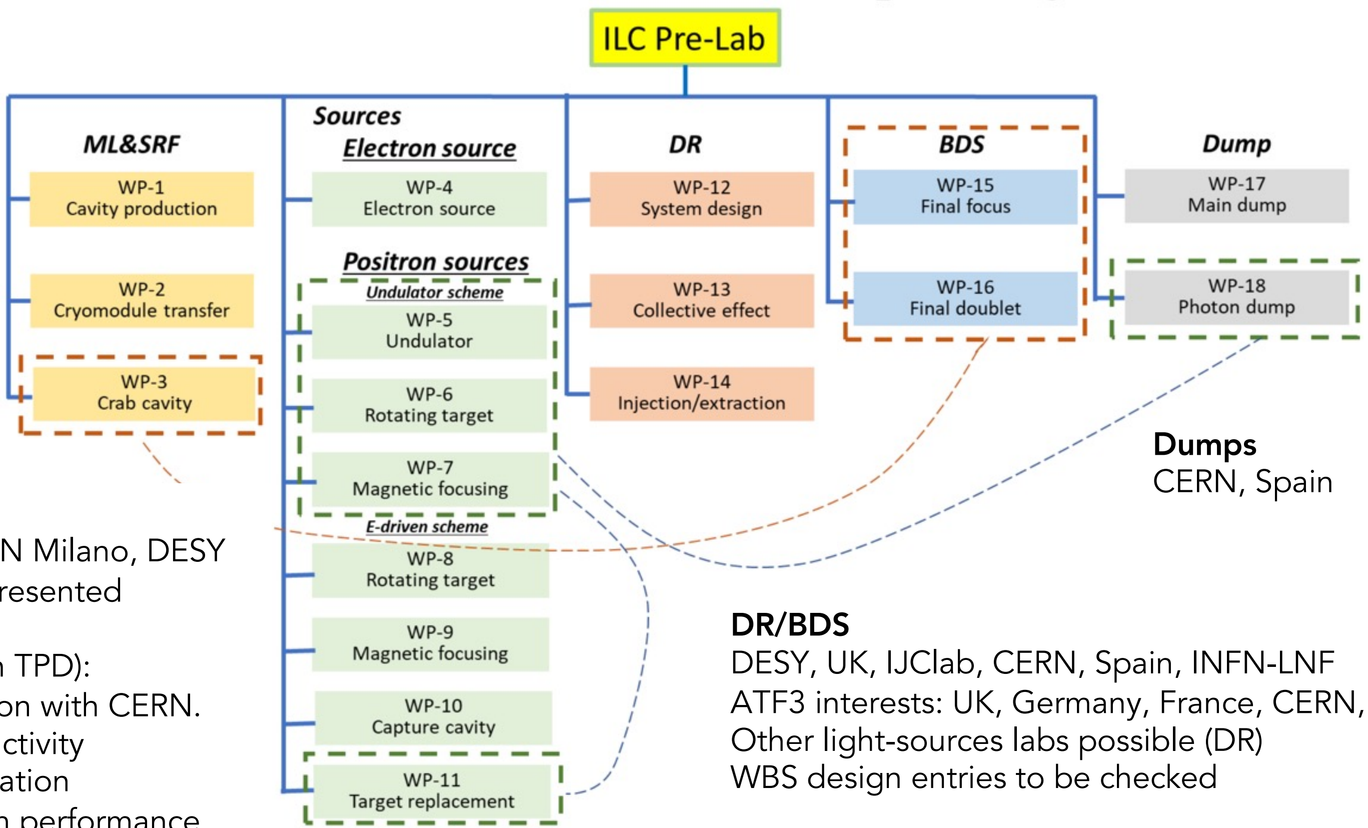




BNL Direct Wind constant gradient tapered double helical coil winding



European Expertise and Pre-Lab Work Packages



Dumps
CERN, Spain

ML & SRF
CEA, CERN, CIEMAT, UK, INFN Milano, DESY
Not all European SRF labs represented

Additionally (in WBS but not in TPD):
- Long term cryo collaboration with CERN.
- HiEff RF another relevant activity
- SRF "basic" R&D for fabrication improvements or long term performance improvements (i.e. for upgrades)

DR/BDS
DESY, UK, IJClab, CERN, Spain, INFN-LNF
ATF3 interests: UK, Germany, France, CERN, Spain
Other light-sources labs possible (DR)
WBS design entries to be checked

Sources
DESY, UK, CERN
IJCLab also, other groups also possible (FCC-ee, Dafne)

S. Stapnes https://agenda.linearcollider.org/event/9203/

1.7.6 Proposals for upgrades or extensions

international development team

The ILC can be upgraded to higher energy and luminosity.

			Z-Pole [4]		Higgs [2,5]			500GeV [1*]		TeV [1*]	
			Baseline	Lum. Up	Baseline	Lum. Up	L Up.10Hz	Baseline	Lum. Up	case B	
Center-of-Mass Energy	E_{CM}	GeV	91.2	91.2	250	250	250	500	500	1000	Energy
Beam Energy	E_{beam}	GeV	45.6	45.6	125	125	125	250	250	500	
Collision rate	f_{col}	Hz	3.7	3.7	5	5	10	5	5	4	
Pluse interval in electron main linac		ms	135	135	200	200	100	200	200	200	
Number of bunches	n_b		1312	2625	1312	2625	2625	1312	2625	2450	
Bunch population	N	10^{10}	2	2	2	2	2	2	2	1.737	
Bunch separation	Δt_b	ns	554	554	554	366	366	554	366	366	
Beam current		mA	5.79	5.79	5.79	8.75	8.75	5.79	8.75	7.60	
Average beam power at IP (2 beams)	P_B	MW	1.42	2.84	5.26	10.5	21.0	10.5	21.0	27.3	
RMS bunch length at ML & IP	σ_z	mm	0.41	0.41	0.30	0.30	0.30	0.30	0.30	0.225	
Emittance at IP (x)	γe^*_x	µm	6.2	6.2	5.0	5.0	5.0	10.0	10.0	10.0	
Emittance at IP (y)	γe^*_y	nm	48.5	48.5	35.0	35.0	35.0	35.0	35.0	30.0	
Beam size at IP (x)	σ^*_x	µm	1.118	1.118	0.515	0.515	0.515	0.474	0.474	0.335	
Beam size at IP (y)	σ^*_y	nm	14.56	14.56	7.66	7.66	7.66	5.86	5.86	2.66	
Luminosity	L	$10^{34}/cm^2/s$	0.205	0.410	1.35	2.70	5.40	1.79	3.60	5.11	Lumi.
Luminosity enhancement factor	H_D		2.16	2.16	2.55	2.55	2.55	2.38	2.39	1.93	
Luminosity at top 1%	$L_{0.01}/L$	%	99.0	99.0	74	74	74	58	58	45	
Number of beamstrahlung photons	n_g		0.841	0.841	1.91	1.91	1.91	1.82	1.82	2.05	
Beamstrahlung energy loss	δ_{BS}	%	0.157	0.157	2.62	2.62	2.62	4.5	4.5	10.5	
AC power [6]	Psite	MW			111	138	198	173	215	300	
Site length	Lsite	km	20.5	20.5	20.5	20.5	20.5	31	31	40	

*There were several typos in the values of the luminosities in the TDR. They have been fixed by CR-0005. https://edmsdirect.desy.de/item/D00000001100895

References

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